Locally Equivalent Weights for Bayesian MrP

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What are we weighting for?[1]

$$\text{Target average response} = \frac{1}{N_T}\sum_{j=1}^{N_T} y_j \approx \frac{1}{N_S}\sum_{i=1}^{N_S} w_i y_i = \text{Weighted survey average response}$$

We can't check this, because we don't observe y_j.

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$$\frac{1}{N_T} \sum_{j=1}^{N_T} \mathbf{x}_j = \frac{1}{N_S} \sum_{i=1}^{N_S} w_i \mathbf{x}_i$$

Such weights satisfy "covariate balance" for $\mathbf{x}$.

You can check covariate balance for any calibration weighting estimator, and any function $f(\mathbf{x})$.

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You can check covariate balance for any calibration weighting estimator, and any function $f(\mathbf{x})$.

Even more, covariate balance is the criterion for a popular class of calibration weight estimators:

Raking calibration weights

"Raking" selects weights that

- Are as "close as possible" to some reference weights
- Under the constraint that they balance some selected regressors.

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Balance checks as sensitivity analysis

One reason to balance $f(\mathbf{x})$ is because we think $\mathbb{E}\left[y|\mathbf{x}\right]$ might plausibly vary $\propto f(\mathbf{x})$, and want to check whether our estimator can capture this variability.

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Balance–informed sensitivity check (BISC) (informal)

Pick a small $\delta > 0$ and an $f(\cdot)$. Define a *new response variable* $\tilde{y}$ such that

$$\mathbb{E}[\tilde{y}|\mathbf{x}] = \mathbb{E}[y|\mathbf{x}] + \delta f(\mathbf{x}).$$

We know the change this is supposed to induce in the target population.

Covariate balance checks whether our estimators produce the same change.

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We know the expected change this perturbation produces in the target distribution:

$$\mathbb{E}\left[\mu(\tilde{y}) - \mu(y)|\mathbf{x}\right] = \frac{1}{N_T}\sum_{j=1}^{N_T}\left(\mathbb{E}\left[\tilde{y}|\mathbf{x}_p\right] - \mathbb{E}\left[y|\mathbf{x}_p\right]\right) = \delta\frac{1}{N_T}\sum_{j=1}^{N_T} f(\mathbf{x}_j)$$

Then, check whether your estimator $\hat{\mu}(\cdot)$ produces the same change for observed $\tilde{y}, y$:

$$\underbrace{\hat{\mu}(\tilde{y}) - \hat{\mu}(y)}_{\text{Replace weighted averages with changes in an estimator}} \overset{\text{check}}{\approx} \delta\frac{1}{N_T}\sum_{j=1}^{N_T} f(\mathbf{x}_j).$$

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When $\hat{\mu}(\cdot) = \hat{\mu}_{\mathrm{CW}}(\cdot)$, BISC recovers the standard covariate balance check.

We will use $\hat{\mu}(\cdot) = \hat{\mu}_{\mathrm{MrP}}(\cdot)$.

BISC for MrP

Suppose I have $\tilde{y}$ such that $\mathbb{E}\left[\tilde{y}|\mathbf{x}\right] = \mathbb{E}\left[y|\mathbf{x}\right] + \delta f(\mathbf{x})$.
Now I need to evaluate $\hat{\mu}_{\text{MrP}}(\tilde{y}) - \hat{\mu}_{\text{MrP}}(y)$.

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Problem: $\hat{\mu}_{\mathrm{MrP}}(\cdot)$ is computed with MCMC.

- Each MCMC run typically takes hours, and
- Output is noisy, and $\hat{\mu}_{\mathrm{MrP}}(\tilde{y}) - \hat{\mu}_{\mathrm{MrP}}(y)$ may be small.

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MrP Local Equivalent Weights (MrPlew)

Form the first-order Taylor series approximation

$$\hat{\mu}_{\text{MrP}}(\tilde{y}) - \hat{\mu}_{\text{MrP}}(y) \approx \sum_{i=1}^{N_S} w_i^{\text{MrP}}(\tilde{y}_i - y_i) \quad \text{where} \quad w_i^{\text{MrP}} := \frac{d}{dy_i}\hat{\mu}_{\text{MrP}}(y).$$

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Computation: The weights are given by weighted averages of posterior covariances[2].

They can be easily computed with standard software[3] **without re–running MCMC**.

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[2] **G.**, Broderick, and Jordan 2018.
[3] We use `brms` (Bürkner 2017).

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Use in BISC: For a wide set of judiciously chosen $f(\cdot)$, check

$$\delta \sum_{i=1}^{N_S} w_i^{\mathrm{MrP}} f(\mathbf{x}_i) \overset{\text{check}}{\approx} \delta \frac{1}{N_T} \sum_{j=1}^{N_T} f(\mathbf{x}_j).$$

Generating $\tilde{y}$

- We have defined BISC in terms of $\tilde{y}$ such that $\mathbb{E}\left[\tilde{y}|\mathbf{x}\right] = \mathbb{E}\left[y|\mathbf{x}\right] + \delta f(\mathbf{x})$
- We have approximated $\hat{\mu}_{\text{MrP}}(\tilde{y}) - \hat{\mu}_{\text{MrP}}(y)$ for $\tilde{y} \approx y$

How to get such a $\tilde{y}$? **Recall y is binary!** Two approaches:

Option 1: Force $\tilde{y}$ to be binary.

1. Make *some* guess $\hat{m}(\mathbf{x}) \approx \mathbb{E}\left[y|\mathbf{x}\right]$
   - E.g. Posterior mean, or
   - Shrunken posterior mean, or
   - Some values that gives the same posterior
2. Take $u_n \overset{iid}{\sim} \text{Unif}(0, 1)$
3. Assume $y_n = \mathbb{I}\left(u_n \leq \hat{m}(\mathbf{x}_n)\right)$
4. Draw $u_n | y_n$
5. Set $\tilde{y}_n = \mathbb{I}\left(u_n \leq \hat{m}(\mathbf{x}_n) + \delta \mathbf{x}_n\right)$

Option 2: Allow $\tilde{y}$ to take generic values.

1. Set $\tilde{y}_n = y_n + \delta f(\mathbf{x}_n)$.

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- Realistic
- Have to pick $\hat{m}(\mathbf{x})$
- $\tilde{Y} - Y_{\mathcal{S}}$ not infinitesimally small
- **Sanity check for theory**

Option 2: Allow $\tilde{y}$ to take generic values.

1. Set $\tilde{y}_n = y_n + \delta f(\mathbf{x}_n)$.

- Not realistic
- No additional assumptions
- $\tilde{Y} - Y_{\mathcal{S}}$ may be infinitesimally small
- **Use for theory**

Theory

BISC Theorem: (sketch)

Take $\tilde{y}_n = y_n + \delta f(\mathbf{x}_n)$.

We state conditions for Bayesian hierarchical logistic regression under which

$$\left| \hat{\mu}_{\text{MrP}}(Y_{\mathcal{S}}) - \hat{\mu}_{\text{MrP}}(Y_{\mathcal{S}}) - \delta \sum_{i=1}^{N_S} w_i^{\text{MrP}} f(\mathbf{x}_i) \right| = \text{Small?}$$

[2]Donsker with uniformly bounded $\mathbb{E}\left[\mathbf{x} f(\mathbf{x})\right]$.

[3]**G.** and Broderick 2024; Kasprzak, **G.**, and Broderick 2025.

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For a very broad class[2] of $\mathcal{F}$.

Uniformity justifies searching for "imabalanced" f.

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The uniformity result builds on our earlier work on uniform and finite–sample error bounds for Bernstein–von Mises theorem–like results[3].

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[3] **G.** and Broderick 2024; Kasprzak, **G.**, and Broderick 2025.

Real Data: Marital Name Change Survey

Analysis of changing names after marriage[4].

- **Target population:** ACS survey of US population 2017–2022[5]
- **Survey population:** Marital Name Change Survey (from Twitter)[6]
- **Respose:** Did the female partner keep their name after marriage?
- For regressors, use bins of age, education, state, and decade married.

Survey observations: $N_S = 4,364$

Target observations (rows): $N_T = 4,085,282$

Uncorrected survey mean: $\frac{1}{N_S} \sum_{i=1}^{N_S} y_i = 0.462$

Raking: $\hat{\mu}_{\mathrm{CW}} = 0.263$

MrP: $\hat{\mu}_{\mathrm{MrP}} = 0.288 \quad (\text{Post. sd} = 0.0169)$

[4] Based on Alexander (2019).

[5] Ruggles et al. 2024.

[6] Cohen 2019.

Covariate balance for primary effects

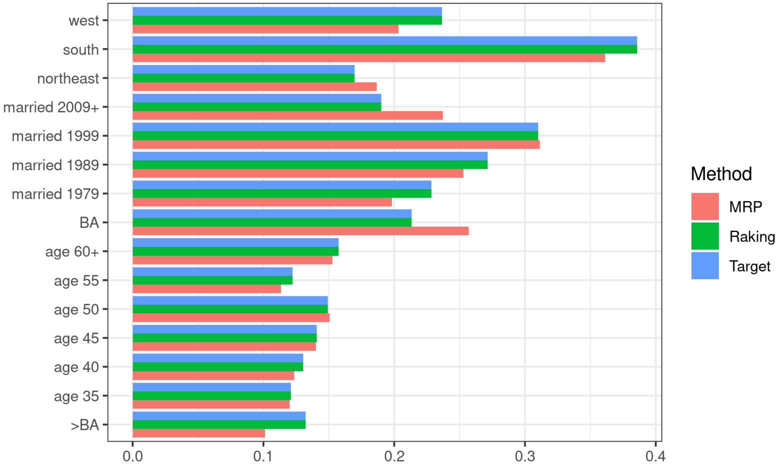

Figure 1: Imbalance plot for primary effects

Covariate balance for interaction effects

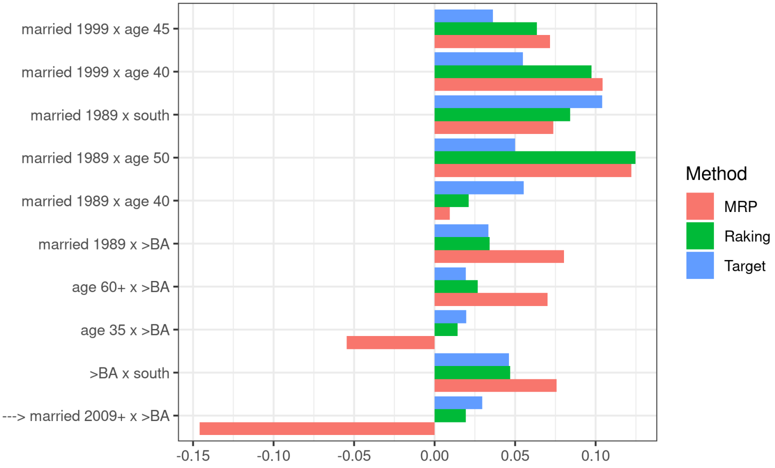

Figure 2: Imbalance plot for select interaction effects

Predictions

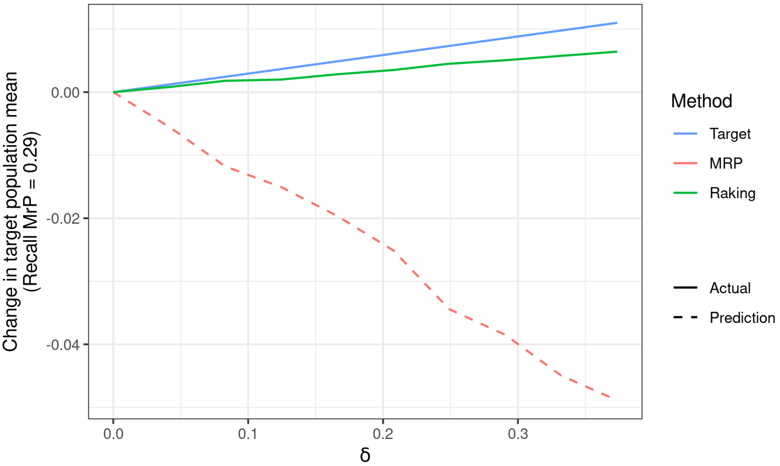

Figure 3: Predictions for the name change dataset

Predictions and actual MCMC results

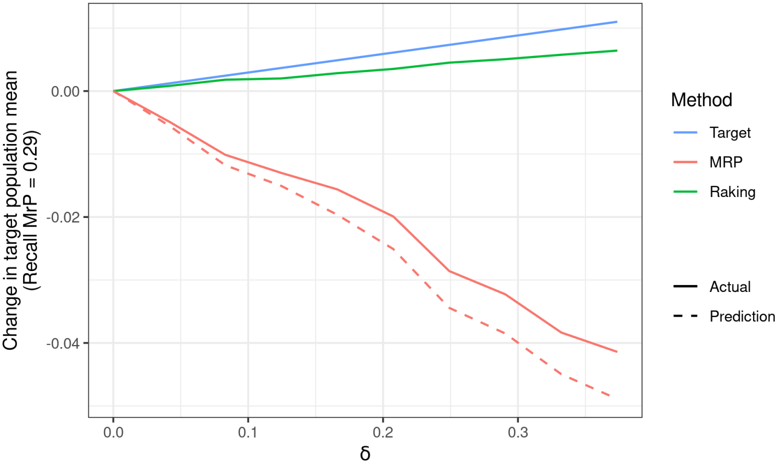

Figure 4: Predictions and refit for the name change dataset

Running ten MCMC refits: 10 hours Computing approximate weights: 16 seconds

Real Data: Lax Philips

Analysis of national support for gay marriage.[7]

- **Target population:** US Census Public Use Microdata Sample 2000
- **Survey population:** Combined national-level polls from 2004
- **Respose:** "Do you favor allowing gay and lesbian couples to marry legally?"
- For regressors, use race, gender, age, education, state, region, and continuous statewide religion and political characteristics, including some analyst–selected interactions.

Survey observations: $N_S = 6,341$

Target observations (rows): $N_T = 9,694,541$

Uncorrected survey mean: $\frac{1}{N_S} \sum_{i=1}^{N_S} y_i = 0.333$

Raking: $\hat{\mu}_{\text{CW}} = 0.33$

MrP: $\hat{\mu}_{\text{MrP}} = 0.337 \quad (\text{Post. sd} = 0.039)$

[7] Based on Kastellec, Lax, and Phillips (2010), see also Lax and Phillips (2009).

Covariate balance for primary effects

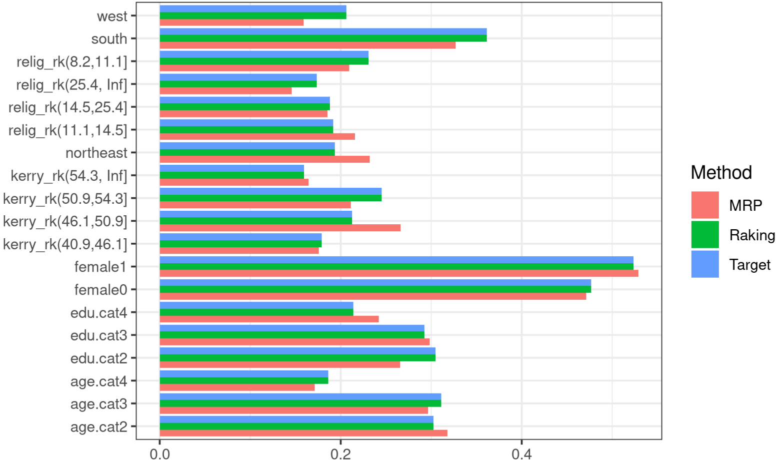

Figure 5: Imbalance plot for primary effects

Covariate balance for interaction effects

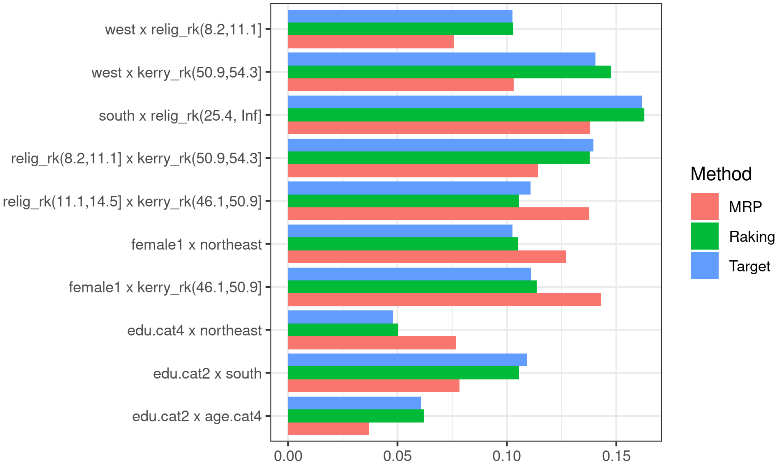

Figure 6: Imbalance plot for select interaction effects

Predictions

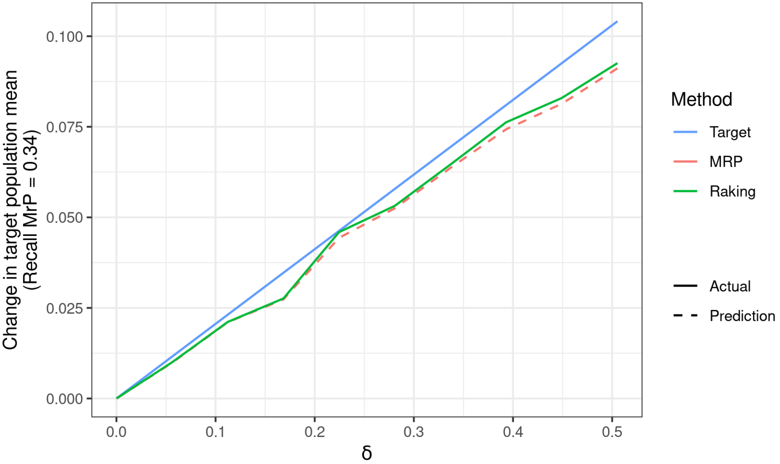

Figure 7: Predictions for the gay marriage dataset

Predictions and actual MCMC results

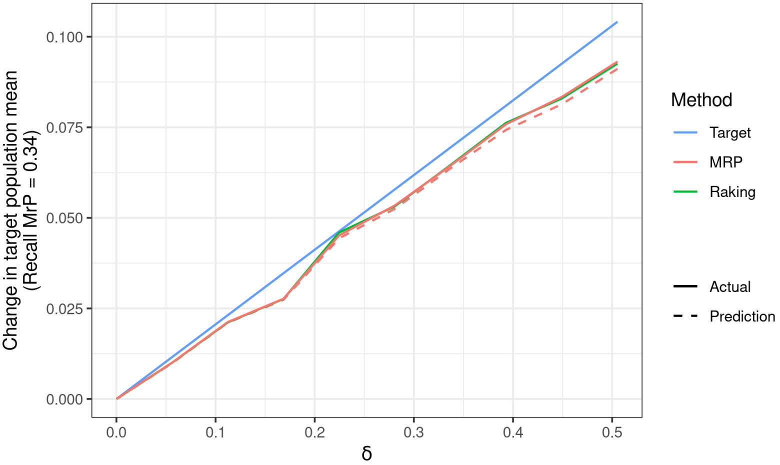

Figure 8: Predictions and refit for the gay marriage dataset

Running ten MCMC refits: 11 hours Computing approximate weights: 23 seconds

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